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A DYNAMIC APPROACH TO INFORMATION SAMPLING AND LEARNING

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14. ABSTRACT
Given that people can process only so many pieces of information, one key aspect of learning is learning which stimulus aspects are goal relevant in the current context. In addition to injecting noise into the decision process, gathering unnecessary information can have costs in terms of time, effort, dollars, fuel, and perhaps lives. In light of these considerations, many category learning models employ selective attention mechanisms that learn which stimulus dimensions are most critical to performance. However, attention in category learning models does not direct what is encoded, but instead establishes decision weights on stimulus dimensions. Likewise, machine learning approaches to feature selection sample features not included in the final subset, and these models do not contextually determine feature relevancy. To address these shortcomings, we develop a model that selectively encodes information during learning as a function of the learner's goals, task demands, and knowledge state. The model consists of two components that are both normative, but lead to apparent non-normative behaviors when linked. One component determines the value of potential sources of information. The value of a piece of information depends on the decision maker's goals and assumptions about (i.e., knowledge of) the world, as well as the cost of the information. The second component of the model reflects the decision maker's knowledge of the world, which is used by the first component to direct information gathering. This learning component of the model is updated by the information samples selected by the first component, completing the cycle of mutual influence. We develop sub-ideal models to both capture human performance and to inform related research in machine learning. Several existing datasets are considered and novel experiments are proposed.

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"A Dynamic Approach to Information Sampling and Learning"

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Objectives:

The primary objectives of the project are unchanged.

Status of Effort:

Dr. Bradley Love's lab has focused on satisfying the objectives of this project. In addition to the PI, three Ph.D. students have contributed to the project. Two of these students are now in postdoctoral positions and the third is starting a job as an assistant professor at Texas Tech. The aforementioned personnel were engaged in data collection, modeling of results, and the dissemination of results through conference presentations and journal article preparation.

Overall, the effort is completed, except for a final review paper that will be written summarizing some of the main findings from the model developed under this contract. Some of those findings are briefly discussed below.

This funded project yielded 19 publications. Some of these publications are high profile, published in *Current Biology*, *Proceedings of the National Academy of Sciences*, and *Behavioral and Brain Sciences*. Some of the contributions attracted positive media attention, included a recent *PLOS ONE* article that was widely featured. The article itself has been viewed around 25K times on *PLOS ONE's* site within its first few weeks of publication. Almost all of these publications involved the integration of modeling and behavioral experiments.

Toward a Model of Learning and Top-Down Attention:

As stated above, the main contribution from this contract is currently be prepared for submission for publication. The model takes a new view on top-down attention during learning. Unlike most models, only a subset of possible information sources are sampled. The model selectively encodes information during learning as a function of the learner's goals, task demands, and knowledge state. The model specifies the interplay of executive processes and category formation. The model consists of two primary components that are both normative, but lead to apparent non-normative behaviors when linked. One component determines the value of potential sources of information. The value of a piece of information depends on the decision maker's goals and assumptions about (i.e., knowledge of) the world. The second component of the model reflects the decision maker's knowledge of the world, which is used by the first component to direct information gathering. This learning component of the model is updated by the information samples selected by the first component, completing the cycle of mutual influence.

A series of simulations have been completed in which this model successfully captures people's eye movement patterns in learning studies. Furthermore, the model has been applied to problems in which there is a signal buried in a great deal of noise. Because the model selectively samples, it is less affected by this preponderance of noise and actually outperforms a Bayesian classifier with

access to all information. This result may be interesting to the machine learning community.

Personnel:

Bradley C. Love, Principal Investigator.

Three Ph.D. students who have since graduated:

Tyler Davis, now an assistant professor at Texas Tech.

Brian Glass, now a postdoc at QMUL.

Ross Otto, now a postdoc at NYU.

Publications:

Mack, M.L., Preston, A.R. & Love, B.C. (in press). Decoding the Brain's Algorithm for Categorization from its Neural Implementation. *Current Biology*.

Blanco, N.J., Otto, A.R., Maddox, W.T., Beevers, C.G. & Love, B.C. (in press). The Influence of Depression Symptoms on Exploratory Decision-Making. *Cognition*.

Giguère, G. & Love, B.C. (2013). Limits in decision making arise from limits in memory retrieval. Proceedings of the *National Academy of Sciences of the United States of America* (PNAS), 110 (19), 7613-7618.

Glass, B.D., Maddox, W.T. & Love, B.C. (2013). Real-Time Strategy Game Training: Emergence of a Cognitive Flexibility Trait. *PLOS ONE*, 8 (8), 1-7.

Sanders, M., Davis, T., & Love, B.C. (2013). Are Better Examples Beautiful or Are Beautiful Examples Better? Exploring the Relationship Between Beauty and Category Structure. *Psychonomic Bulletin & Review*, 20, 566-573.

Knox, W.B., Glass, B.D., Love, B.C., Maddox, W.T., & Stone, P. (2012). How humans teach agents. *International Journal of Social Robotics*, 4 (4), 409-421.

Davis, T., Love, B.C., & Maddox, W.T. (2012). Age-related Declines in the Fidelity of Newly Acquired Category Representations. *Learning and Memory*, 19, 325-329.

Davis, T., Love, B.C., & Preston, A.R. (2012). Striatal and Hippocampal Entropy and Recognition Signals in Category Learning: Simultaneous Processes Revealed by Model-based fMRI. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 38,821-839. (special issue on Theory and data in categorization: Integrating computational, behavioral, and cognitive neuroscience approaches).

Knox, W.B., Otto, A.R., Stone, P., & Love, B.C. (2012). The Nature of Belief-Directed Exploratory Choice in Human Decision-Making. *Frontiers in Psychology*, 2, 398.

Otto, A.R., Markman, A.B., & Love, B.C. (2012). Taking More, Now: The Optimality of Impulsive Choice Hinges on Environment Structure. *Social Psychological and Personality Science*, 3(2), 131-138.

Davis, T., Love, B.C., & Preston, A.R. (2012). Learning the Exception to the Rule: Model-Based fMRI Reveals Specialized Representations for Surprising Category Members. *Cerebral Cortex*, 22, 260-273.

Jones, M. & Love, B.C. (2011). Bayesian Fundamentalism or Enlightenment? On the Explanatory Status and Theoretical Contributions of Bayesian Models of Cognition. *Behavioral and Brain Sciences*, 34, 169-231. (target article and response to commentaries).

Goldwater, M.B., Tomlinson, M.T., Echols, C.H., & Love, B.C. (2011). Structural Priming as Structure-Mapping: Children Use Analogies from Previous Utterances To Guide Sentence Production. *Cognitive Science*, 35, 156-170.

Sakamoto, Y., & Love, B.C. (2010). Learning and Retention through Predictive Inference and Classification. *Journal of Experimental Psychology: Applied*, 16, 361-377

Tomlinson, M.T., & Love, B.C. (2010). When Learning to Classify by Relations Is Easier Than by Features. *Thinking & Reasoning*, 16, 372-401.

Otto, A.R., Gureckis, T.M., Markman, A.B., & Love, B.C. (2010). Regulatory Fit and Systematic Exploration in a Dynamic Decision-Making Environment. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 36(3), 797-804.

Otto, A.R., & Love, B.C. (2010). You Don't Want To Know What You're Missing: When Information about Forgone Rewards Impedes Dynamic Decision Making. *Judgment and Decision Making*, 5, 1-10.

Davis, T., & Love, B.C. (2010). Memory for Category Information is Idealized through Contrast with Competing Options. *Psychological Science*, 21, 234-242.

Gureckis, T. M., & Love, B. C. (2010). Direct Associations or Internal Transformations? Exploring the Mechanisms Underlying Sequential Learning Behavior. *Cognitive Science,* 34, 10-50.

Interactions/Transitions:

Some of the PI's most rewarding interactions have been with other researchers at the program review meeting. The composition of the program is ideal as it brings together mathematically sophisticated psychologists and machine learning people who are interested in human cognition and decision making. Likewise, the PI has interacted with members of AFRL. For example, the PI participated in a workshop funded by AFOSR that AFRL on "Persistent & Generative Cognitive Models". These interactions and flow of information are prized by the PI. Through these interactions, new collaborations have emerged, such as one with computer scientist Dr. Jerry Zhu concerning Bayesian optimal instruction of humans.

Related to the President's new BRAIN initiative, the PI attended a workshop sponsored by the NSF in Washington, D.C. on "Integrating Approaches to Computational Cognition" that aimed to support the agenda broadly advanced by AFOSR's Cognition and Decision program (AFOSR program officer Dr. Jay Myung was in attendance).

The PI and his students have been active in both domestic and interactional conferences, as well as giving frequent invited talks, which are listed below.

Invited talks:

8/2013	"Limits in Decision Making Reflect Limits in Memory Retrieval", dunnhumby Corportation, London, UK.
6/2013	AECT International Conference on the Frontier in e-Learning Research, Taipei, Taiwan.
5/2013	"Limits in Decision Making Reflect Limits in Memory Retrieval", Workshop on Integrating Approaches to Computational Cognition, Sponsored by the National Science Foundation, Arlington, VA, USA.
3/2013	"Limits in Decision Making Reflect Limits in Memory Literature", Computational Models of Cognition Workshop, Birkbeck.
2/2013	"Limits in Decision Making Reflect Limits in Memory Literature", London JDM group.
2/2013	"Linking Brain, Behaviour, and Computation in Category Learning", City University London
11/2012	"Cognitive Psychology in Service of Retail", dunnhumby corporation, London, UK.

9/2012	"Linking Brain, Behaviour, and Computation in Category Learning", Center for Cognitive Neuroscience. University of Pennsylvania.
8/2012	Talks at National Taiwan University of Science and Technology (NTUST), Taipei, Taiwan, and National Central University (NCU), Jhongli City, Taiwan.
8/2012	Invited symposium, "Thirty years of Marr's Vision: Levels of Analysis in Cognitive Science ", Annual Meeting of the Cognitive Science Society, Sapporo, Japan.
6/2012	"Boosting Executive Function through Video Game Training", Cognitive Control and Associative Learning workshop, Exeter, UK.
4/2012	"Linking Brain, Behaviour, and Computation in Category Learning", Swansea University.
3/2012	"Linking Brain, Behaviour, and Computation in Category Learning", Wellcome Functional Imaging Laboratory, UCL.
3/2012	"Linking Brain, Behaviour, and Computation in Category Learning", University of Oxford.
3/2012	"Linking Brain, Behaviour, and Computation in Category Learning", University of Warwick.
2/2012	"Linking Brain, Behaviour, and Computation in Category Learning", Birkbeck, University of London.
12/2011	"Learning the exception to the rule," Department of Linguistics, University of Texas at Austin
4/2011	Panellist, "Sustainable Design Symposium 2011," hosted by Kate Catterall.
2/2011	"The Memory and Attention Interface," Brown University.
2/2011	"Attention as a Consequence of Dynamic Decision Making," UNSW.
1/2011	"Attention as a Consequence of Dynamic Decision Making," UCL.
11/2010	"Looking to Learn, Learning to Look: Attention Emerges from Cost Sensitive Information Sampling", Workshop on Persistent & Generative Cognitive Models, funded and hosted by Air Force Research Laboratory (Mesa, AZ).